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(54) **METHOD OF GENERATING VIEW-DEPENDENT COMPENSATED IMAGES**

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H04N 17/00 (2006.01)

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USPC 353/121, 122; 348/189; 250/252.1

See application file for complete search history.

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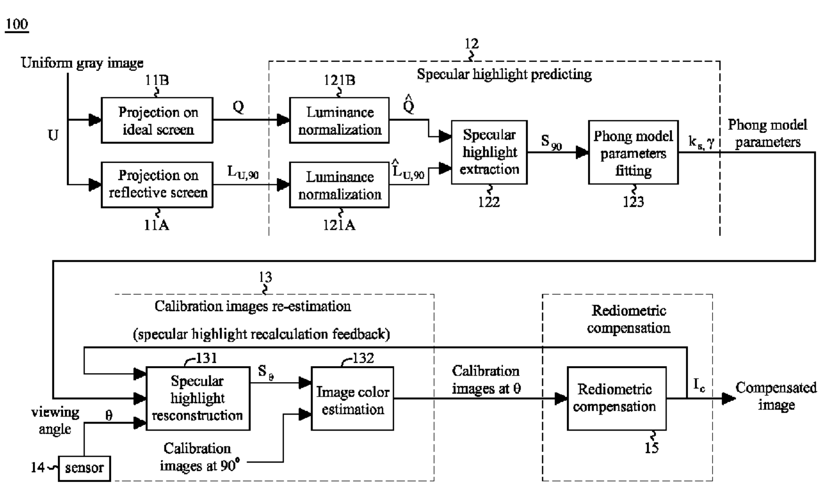
(57) **ABSTRACT**

A method of generating view-dependent compensated images is disclosed. A uniform image is projected on a reflective screen, resulting in a first captured image. The distribution of specular highlight is predicted according to the first captured image, thereby obtaining model parameters. Calibration images are estimated according to the model parameters and a viewing angle, and a compensated image is generated according to the calibration images at the viewing angle.

12 Claims, 3 Drawing Sheets



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G12B 13/00	(2006.01)
H04N 9/31	(2006.01)
G03B 21/56	(2006.01)
G03B 21/14	(2006.01)
H04N 9/77	(2006.01)
H04N 13/04	(2006.01)
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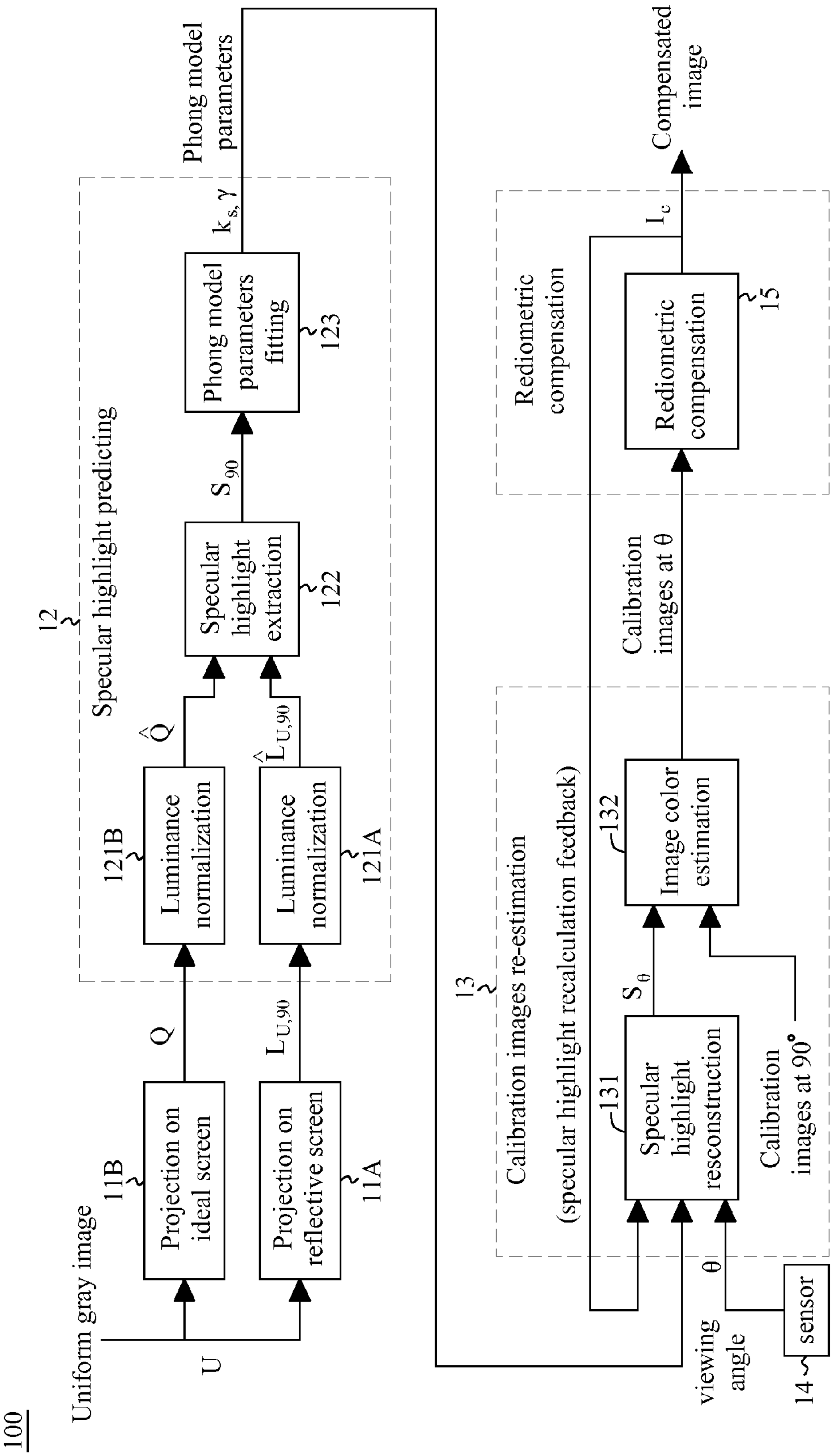
100
Uniform gray image
U
11B
Projection on ideal screen
11A
Projection on reflective screen
Q
$L_{U,90}$
12
Specular highlight predicting
121B
Luminance normalization
121A
Luminance normalization
$\hat{Q}$
$\hat{L}_{U,90}$
Specular highlight extraction
122
S_{90}
Phong model parameters fitting
123
k_s, γ
Phong model parameters
13
Calibration images re-estimation
(specular highlight recalculation feedback)
131
Specular highlight resconstruction
S_θ
132
Image color estimation
Calibration images at 90°
Calibration images at θ
Rediometric compensation
Rediometric compensation
15
I_c
Compensated image
viewing angle
θ
sensor
14

FIG.1

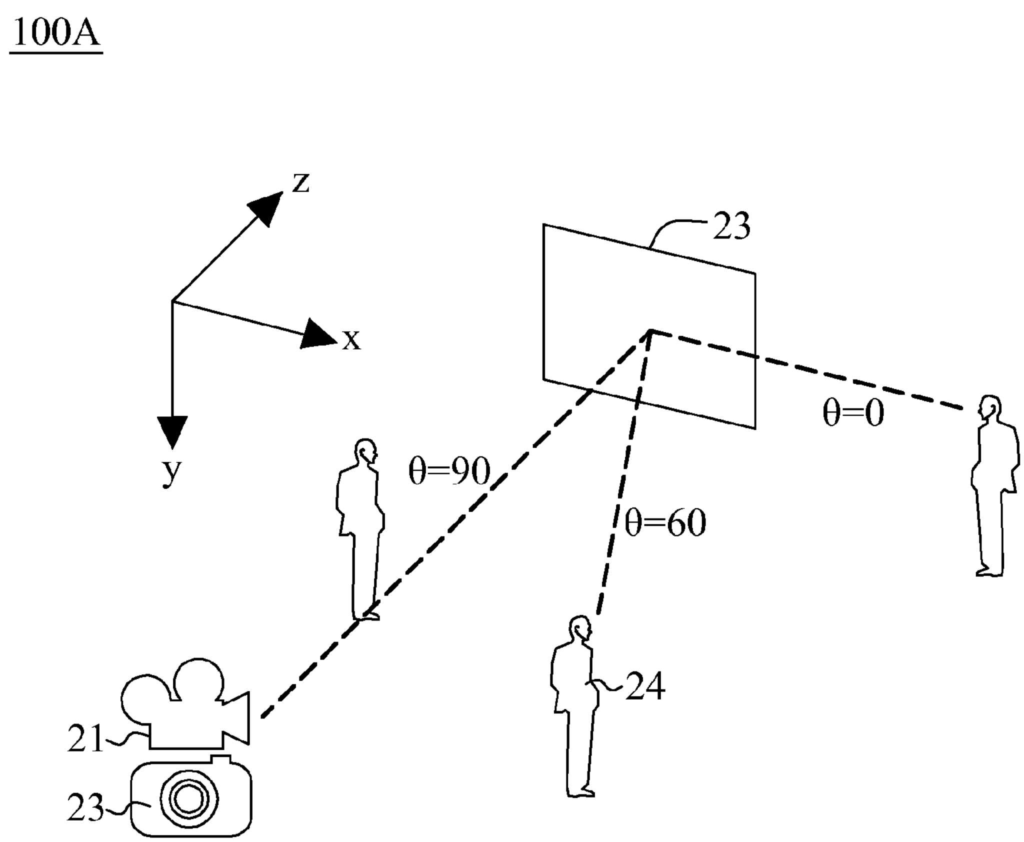

FIG.2

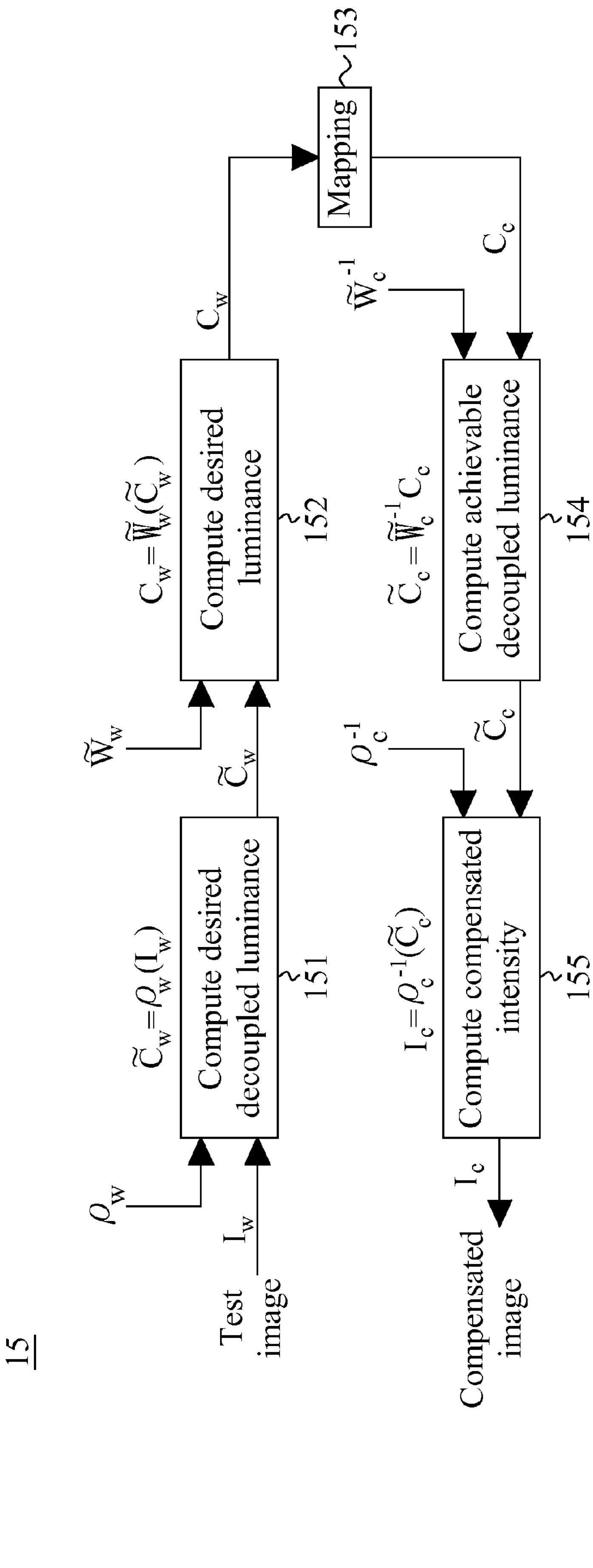
15
Test image
I_w
ρ_w
$\tilde{C}_w = \rho_w(I_w)$
Compute desired decoupled luminance
151
$\tilde{W}_w$
$\tilde{C}_w$
$C_w = \tilde{W}_w(\tilde{C}_w)$
Compute desired luminance
152
C_w
Mapping
153
C_c
$\tilde{W}_c^{-1}$
$\tilde{C}_c = \tilde{W}_c^{-1} C_c$
Compute achievable decoupled luminance
154
$\tilde{C}_c$
ρ_c^{-1}
$I_c = \rho_c^{-1}(\tilde{C}_c)$
Compute compensated intensity
155
I_c
Compensated image

FIG.3

METHOD OF GENERATING VIEW-DEPENDENT COMPENSATED IMAGES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/697,697, filed on Sep. 6, 2012 and entitled "Compensating Specular Highlights for Non-Lambertian Projection Surfaces," the entire contents of which are incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention generally relates to an image projector, and more particularly to architecture of generating view-dependent compensated images for a non-Lambertian surface.

2. Description of Related Art

Using an image projector in a mobile phone or digital camera greatly overcomes the screen size limitation of the handheld device and allows the image to be conveniently projected onto a bigger area on any nearby surface, such as a wall. Ideally, we would like the handheld projector to be able to project a clear image regardless of the physical characteristics of the projection surface. In practice, however, the projection surface available in the surroundings is often far from ideal and causes distortions to the projected image. As a result, compensation must be applied to the image before projection to counteract the non-ideal characteristics of the projection surface.

One fundamental assumption of most compensation techniques is that the camera is placed where the viewer is supposed to be. This assumption is easily violated since a projector-camera (procam) device can be placed at an angle with respect to the viewer. This nullifies the compensation calculated based on the assumption that the viewer and the camera are aligned or collocated at the same place. Thus, for non-Lambertian screens one should design a more general compensation algorithm that takes the viewing direction into consideration.

As a result, a need has arisen to propose a novel scheme of generating view-dependent compensated images for a non-Lambertian surface.

SUMMARY OF THE INVENTION

In view of the foregoing, it is an object of the embodiment of the present invention to provide a method of generating view-dependent compensated images for a non-Lambertian surface with multifold advantages. First, the embodiment provides a simple scheme that does not require additional projectors or cameras to reconstruct the reflection property of the surface—only one camera and one projector suffice. Second, the embodiment predicts the calibration images for different viewing angles from those captured at a single viewing angle, which greatly extends the capability of a procam system. Third, the embodiment introduces a feedback to re-estimate the specular light iteratively, which avoids over-compensation.

According to one embodiment, a procam system comprised of a projector and a camera is provided. A uniform image is projected on a reflective screen, resulting in a first captured image. The distribution of specular highlight is predicted according to the first captured image, thereby obtaining model parameters. Calibration images are estimated according to the model parameters and a viewing angle. A compensated image is generated according to the calibration images at the viewing angle.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a block diagram illustrative of architecture of generating view-dependent compensated images for a non-Lambertian surface according to one embodiment of the present invention;

FIG. **2** shows an exemplary embodiment, to which a projector-camera system may be adapted; and

FIG. **3** shows a detailed block diagram of the radiometric compensation unit of FIG. **1**.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1** shows a block diagram illustrative of architecture **100** of generating view-dependent compensated images for a non-Lambertian (or reflective) surface according to one embodiment of the present invention. The composing blocks of FIG. **1** may be implemented by hardware or be performed, for example, by a digital signal processor.

FIG. **2** shows an exemplary embodiment, to which a projector-camera (procam) system **100**A comprised of a projector **21** and a camera **22** bound together may be adapted. However, the embodiment, with minor modification, may also be adaptable to a procam system comprised of multiple projectors and cameras. As shown in FIG. **2**, as a viewer **24** moves along xz-plane, a viewing angle θ, measured in degree, is thus defined. In the embodiment, the viewing angle θ is 90 when the viewer **24** stands right in front of a reflective screen **23**.

As shown in FIG. **1**, in unit **11**A, a uniform image, e.g., a uniform gray image, U is projected on the reflective screen **23** (FIG. **2**), resulting in a (first) captured image $L_{U,90}$.

While most of light is evenly scattered, a portion of light rays directly reflect as if the surface of the reflective screen **23** is a mirror. The mirror-like reflection of light is commonly known as specular highlight. The architecture **100**, therefore, utilizes a unit for predicting distribution of the specular highlight. The embodiment adopts Phong model, as disclosed by B. T. Phong, "Illumination for computer generated pictures," *Communications of the ACM*, vol. 18, no. 6, pp. 311-317, 1975, the disclosure of which is incorporated herein by reference.

Specifically, the specular highlight predicting unit **12** includes a luminance normalization sub-unit **121**A for normalizing the (first) captured image $L_{U,90}$, resulting in a (first) normalized captured image $\hat{L}_{U,90}$, with value ranging from 0 to 1, denoting spatial variation of the luminance. In addition to the specular highlight, the luminance variation is also caused by vignetting, introduced by imperfection of lens, which often results in luminance reduction at the periphery of a photo. Therefore, vignetting factor need be estimated and excluded before reconstructing the Phong model.

Specifically, the vignetting effect may be calculated, in unit **11**B, by projecting the same uniform image U onto an ideal projection screen (not shown), which is assumed to be highly, if not perfectly, diffusive, resulting in a (second) captured image Q. The (second) captured image Q is then normalized, by a luminance normalization sub-unit **121**B, to obtain a (second) normalized captured image $\hat{Q}$, which is the luminance variation caused by pure vignetting. Subsequently, in specular highlight extraction sub-unit **122**, specular highlight S_{90} may be extracted by

$$S_{90}(x, y) = \frac{\hat{L}_{U,90}(x, y)}{\hat{Q}(x, y)}.$$

Afterwards, in Phong model parameters fitting sub-unit **123**, Phong model parameters k_s and γ may be obtained, for example, by linear regression, for describing the specular highlight I_s as

$$I_s = k_s(\hat{R} - \hat{V})^{\gamma} i_s$$

where k_s is a specular reflection constant, $\hat{R}$ is a direction of a perfectly reflected light, $\hat{V}$ is a direction toward the viewer **24**, γ is a shininess constant for screen material, and i_s is intensity of a light source.

After obtaining parameters (e.g., k_s and γ) of model for predicting distribution of the specular highlight, the process of the architecture **100** proceeds to a unit **13** of estimating calibration images. Specifically, in a specular highlight reconstruction sub-unit **131**, a specular highlight S_θ at an arbitrary viewing angle θ may be reconstructed or predicted based on the model parameters and the viewing angle θ, obtained, for example, by a sensor **14**. Subsequently, in an image color estimation sub-unit **132**, luminance difference D_θ between the specular highlight seen at 90° C. and θ is first generated, (that is, $D_\theta = s_L(S_\theta - S_{90})$, where s_L is a scaling factor), and plural calibration images at θ are estimated by adding the luminance difference D_θ (of S_{90} and S_θ) to calibration images at 90°. That is,

$$L_{M,\theta} = L_{M,90} + n(S_\theta - S_{90}), M \in \{R, G, B, U, S\}$$

where n is a scaling factor.

In the embodiment, the calibration images $L_{M,\theta}$ comprise four uniform-colored images (red, green, blue and gray) and one color ramp image consisting of pixels from gray-level 0 to gray-level 255.

Still referring to FIG. **1**, a radiometric compensation unit **15** is utilized to generate a compensated image I_c according to the calibration images $L_{M,\theta}$ at θ. FIG. **3** shows a detailed block diagram of the radiometric compensation unit **15** of FIG. **1** for generating a compensated image I_c that, when projected on the reflective (or colored) screen **23**, is perceived almost the same as projection of a test image I_w on a white screen. Specifically, in sub-unit **151**, the test image I_w is converted first to a desired decoupled luminance $\tilde{C}_w$ by a mapping ρ w, which is a monotonic function in the embodiment. Then, in sub-unit **152**, a desired luminance C_w is generated by multiplying the decoupled luminance $\tilde{C}_w$ by a color matrix $\tilde{W}_w$, which captures coupling between each color channel of the projector **21** and the camera **22**. Here, the desired luminance C_w serves as a simulation of the perceived luminance supposing the test image I_w is projected on the white screen. Thereafter, the desired luminance C_w is subject to mapping **153**, e.g., tone mapping, that compresses dynamic range within a recoverable range while performing compensation toward photometric correctness, therefore resulting in a mapped desired luminance C_c. The tone mapping, however, reduces image contrast. Therefore, tradeoff between the photometric correctness and the contrast should be optimized, for example, by maximizing the number of pixels that lie within the recoverable dynamic range, while preserving as much contrast as possible. Afterwards, sub-unit **154** obtains an achievable decoupled luminance $\tilde{C}_c$, according to the mapped desired luminance C_c, by decoupling the color channels. Finally, in sub-unit **155**, the achievable decoupled luminance $\tilde{C}_c$ is mapped to an 8-bit pixel value, therefore resulting in the compensated image I_c.

The luminance of the projected light determines the chroma and the intensity of the specular highlight. In particular, when a compensated image is projected, the specular highlight slightly differs from that estimated in the initial condition, under which the calibration image is projected. This often leads to over-compensation. Accordingly, as shown in FIG. **1**, specular highlight feedback is incorporated to recalculate, in sub-unit **131**, the specular highlight S_θ based on the content of the compensated image I_c. In the embodiment, the intensity of specular highlight i_s is changed to i_c according to the following equation:

$$i_c = i_s \frac{\bar{I}_c}{\bar{U}}$$

where $\bar{U}$ and $\bar{I}_c$ are average luminance of U and I_c, respectively, for example, by iterating the feedback loop three times.

Although specific embodiments have been illustrated and described, it will be appreciated by those skilled in the art that various modifications may be made without departing from the scope of the present invention, which is intended to be limited solely by the appended claims.

What is claimed is:

1. A method of generating view-dependent compensated images, comprising:
- providing a procam system comprised of a projector and a camera;
- projecting a uniform image on a reflective screen, resulting in a first captured image;
- projecting the uniform image onto an ideal projection screen that is substantially diffusive, resulting in a second captured image;
- predicting distribution of specular highlight according to the first captured image and the second captured image, thereby obtaining model parameters;
- estimating calibration images according to the model parameters and a viewing angle; and
- generating a compensated image according to the calibration images at the viewing angle.

2. The method of claim **1**, wherein the distribution of specular highlight is predicted based on Phong model, thereby obtaining Phong model parameters by linear regression.

3. The method of claim **1**, wherein the step of predicting the distribution of specular highlight comprises:
- normalizing the first captured image, resulting in a first normalized captured image;
- normalizing the second captured image, resulting in a second normalized captured image; and
- extracting the specular highlight as a ratio of the first normalized captured image to the second normalized captured image.

4. The method of claim **1**, wherein the step of estimating the calibration images comprises:
- reconstructing a specular highlight at the viewing angle based on the model parameters and the viewing angle;
- generating luminance difference between a specular highlight seen at 90 degrees and the viewing angle; and
- estimating a plurality of calibration images at the viewing angle by adding the luminance difference to calibration images at 90 degrees.

5. The method of claim **4**, wherein the plurality of calibration images comprises one color ramp image and four uniform-colored images of red, green, blue and gray, respectively.

6. The method of claim **4**, wherein the specular highlight is reconstructed further based on the compensated image by feeding back the compensated image before reconstructing the specular highlight.

7. The method of claim **1**, wherein the viewing angle is provided by a sensor.

8. The method of claim **1**, when the compensated image is projected on the reflective screen, the compensated image is perceived substantially the same as projection of a test image on a white screen.

9. The method of claim **8**, wherein the step of generating the compensated image comprises:

converting the test image to a desired decoupled luminance by first mapping;

generating a desired luminance by multiplying the decoupled luminance by a color matrix, which captures coupling between each color channel of the projector and the camera;

subjecting the desired luminance to second mapping, that compresses dynamic range within a recoverable range while performing compensation toward photometric correctness, therefore resulting in a mapped desired luminance;

obtaining an achievable decoupled luminance according to the mapped desired luminance by decoupling the color channels; and

third mapping the achievable decoupled luminance to an 8-bit pixel value, therefore resulting in the compensated image.

10. The method of claim **9**, wherein the first mapping is a monotonic function.

11. The method of claim **9**, wherein the second mapping is tone mapping.

12. The method of claim **1**, wherein the projector and the camera of the procam system are bound together.

* * * * *